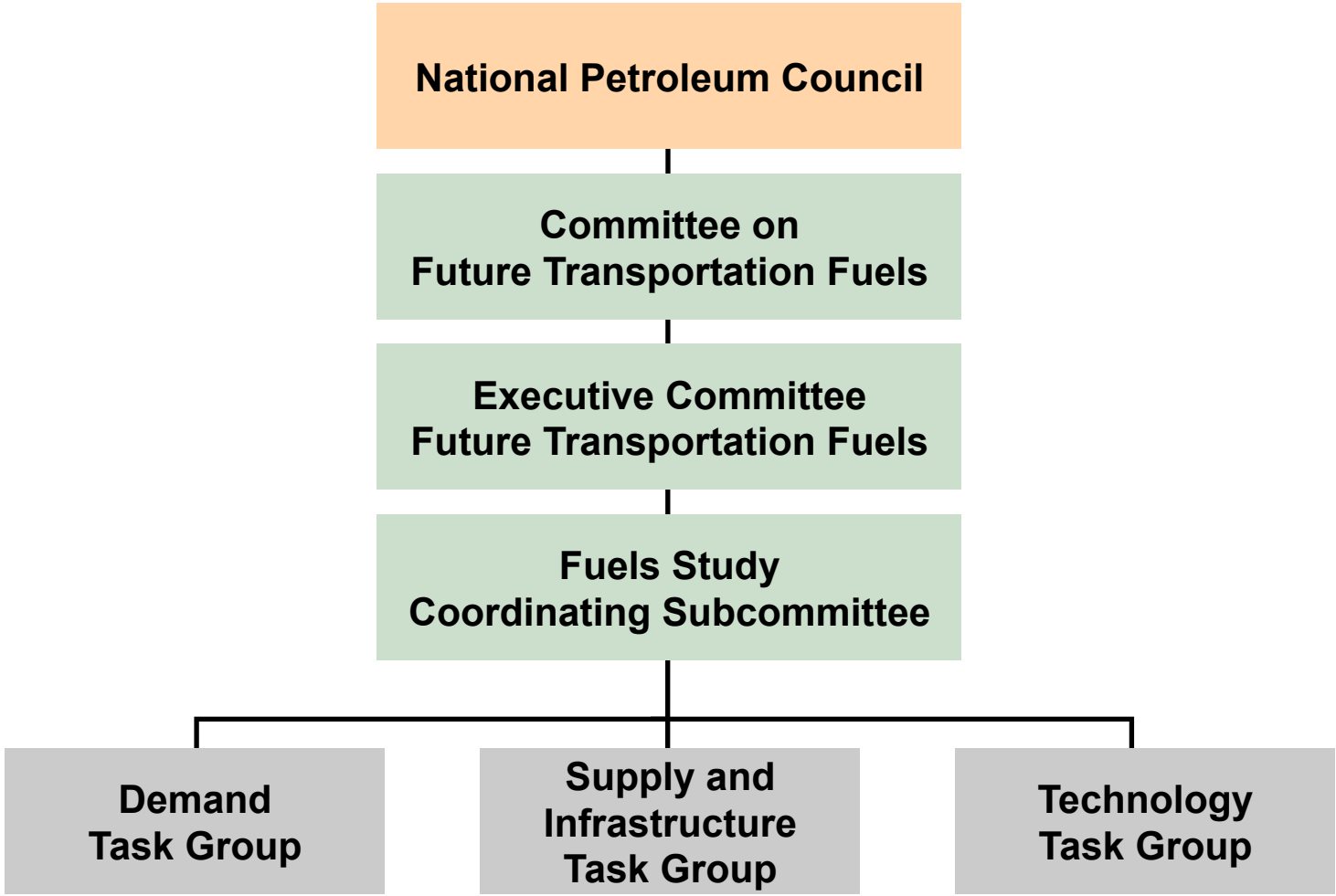
Advancing Technology for America's Transportation Future

National Petroleum Council
August 1, 2012

NPC Request from Energy Secretary Chu

- **Examine opportunities to accelerate Future Transportation Fuels prospects through 2050 for auto, truck, air, rail, and waterborne transport**
- **Address fuel demand, supply, infrastructure, and technology**
- **Factors to consider include:**
  - Infrastructure
  - Technological advances
  - Energy efficiency
  - Environmental, e.g., impact on carbon, land, and water
  - Energy Security
  - Economic competitiveness
- **Additional question:** (Supplemental Letter April 30, 2010)
  - What actions could industry and government take to stimulate the technological advances and market conditions needed to reduce life-cycle greenhouse gas emissions in the U.S. transportation sector by 50 percent by 2050 relative to 2005 levels, while enhancing the nation's energy security and economic prosperity?

Fuels Study Structure



Fuels Study Leadership

Study Executive Committee Leadership

Chair	Clarence Cazalot (Marathon)
Government Cochair	Daniel Poneman (DOE)
Demand Vice Chair	James Owens (Caterpillar)
Supply & Infrastructure Vice Chair	John Watson (Chevron)
Technology Vice Chair	John Deutch (MIT)
Secretary	Marshall Nichols (NPC)

Coordinating Subcommittee

Chair	Linda Capuano (Marathon)
Government Cochair	David Sandalow (DOE)
Supply & Infrastructure Task Group Chair	Shariq Yosufzai (Chevron)
Demand Task Group Chair	Deanne Short (Caterpillar)
Technology Task Group Chair	Stephen Brand (ConocoPhillips)
Secretary	Mark Palfrey (NPC)

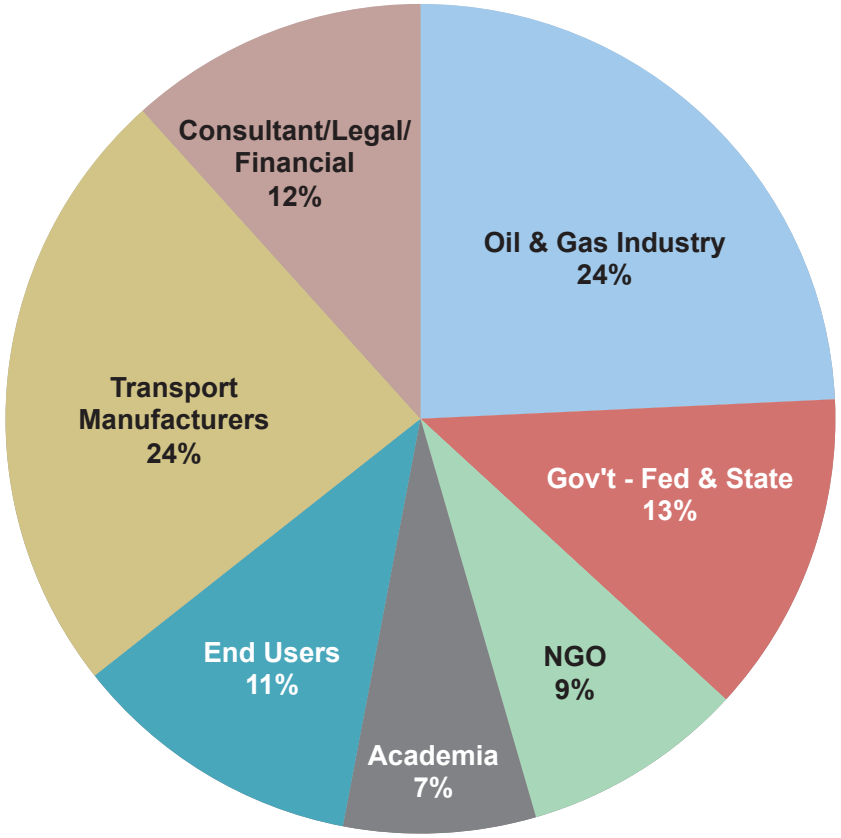
Members

Anthony Boccanfuso (University of S.C.)	Peggy Montana (Shell)
Chris W. Erickson (ExxonMobil)	Richard Newell (Duke University)
Michael Gallagher (Westport Innovations)	Alan Taub (General Motors)
Mitch Jackson (FedEx)	Arthur Rypinski (Dept of Transportation)
Henry Kelly (DOE)	Chris Sultemeier (Wal-Mart)
Jan Mares (Resources For the Future)	William Reinert (Toyota)
	Todd Werpy (Archer Daniels Midland)

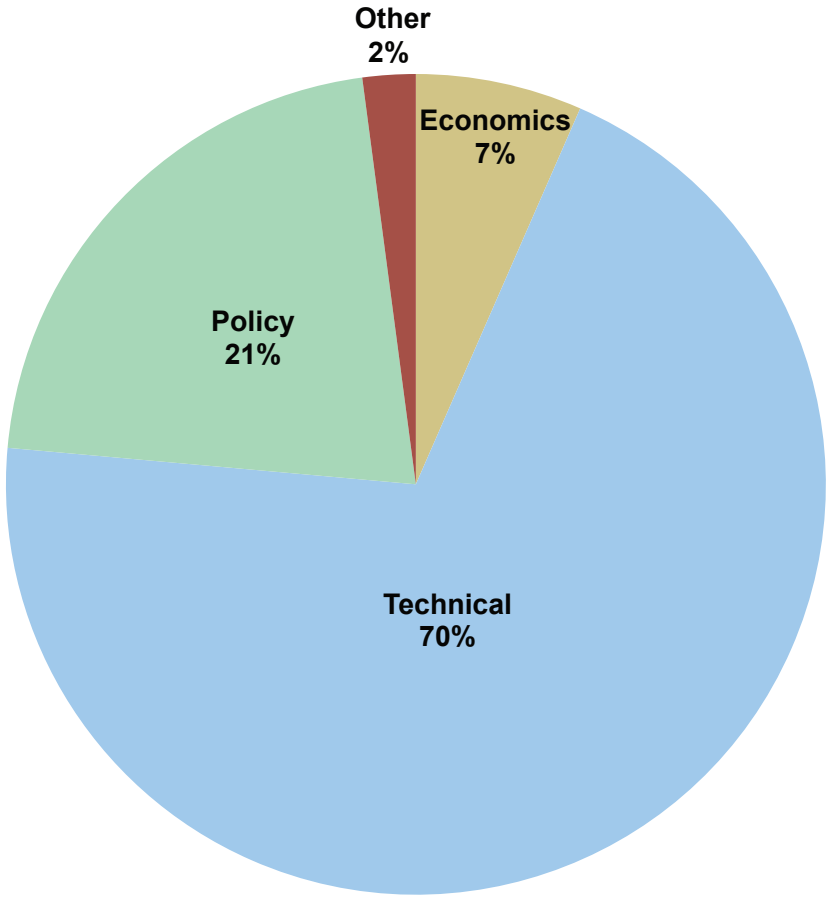
Fuels Study Demographics

Over 300 Participants

By Organization Type



By Skill



Guiding Principles

- Scope then execute
- Clarify assumptions
- Examine the facts before discussing policy
- Consider the impact through three lenses
  - Environment
  - Economic
  - Energy Security
- Diversity of thought
- Promote consensus based leadership
- Maximize the use of prior studies
- Communicate and outreach throughout the study

Technology Briefings

Vehicle Technologies

Briefing Topic	Sponsoring Organization
Plug-in Electric Vehicle Pilots	Accenture
Carbon Fiber for Vehicles	BMW/SGL Automotive Group
Vehicle Electrification	General Motors
Light Duty Vehicle Technologies	National Academies
Medium and Heavy Duty Vehicles	SAE International

Fuel Technologies

Briefing Topic	Sponsoring Organization
Biofuels/Artificial Photosynthesis	ANSER Solar Energy Research Center
Advanced Biofuels	Defense Advanced Research Projects Agency
Advanced Biofuels	Iowa State University
Future of Natural Gas	Massachusetts Institute of Technology
Alternative Liquid Transportation Fuels	National Academies
Hydrogen, Biofuels, Advanced ICEs/HEVs/PHEVs	National Academies
Coal and Fuels Program	National Energy Technology Lab
XTL Technologies (e.g. coal-to-liquid)	Noblis/Pennsylvania State University
Biomass	U.S. Department of Energy
Fuel and Lubricant Technologies	U.S. Department of Energy
Fuel Cell Technologies	U.S. Department of Energy
Renewable Natural Gas	U.S. Department of Energy

Technology Briefings

Environment and Efficiency

Briefing Topic	Sponsoring Organization
Potential Transportation Energy Efficiency	Carnegie Mellon University
Light Duty Vehicle GHG Technical Activities	Environmental Protection Agency
US Drive (formerly FreedomCAR)	National Academies
Reducing GHG Emissions from U.S. Transportation	Pew Center on Global Climate Change
Transportation Options for Reducing GHG Emissions	Precourt Institute of Energy

Infrastructure and Investment

Briefing Topic	Sponsoring Organization
Transportation Fuel Technology Investment	Advanced Research Projects Agency - Energy
Visualizing U.S. Urbanization and Transportation Trends	Toyota Research Institute
Clean Cities	U.S. Department of Energy
Electric Vehicle Infrastructure Initiatives	U.S. Department of Energy
Hybrid/Electric Systems R&D Investment	U.S. Department of Energy
Vehicle Miles Travelled Projections	U.S. Department of Transportation

Ongoing Outreach and Review Process

2010	✓	Dec 3	Subject Matter Expert Review
2011	✓	Jan 18	NGO Outreach Event
	✓	Feb 15	Fuel Cell Hydrogen Energy Association
	✓	Feb 16	Fuels/Resources: NGO Outreach Event
	✓	Feb 22	Fuels/Resources: Natural Gas Round Table
	✓	Mar 9	Subject Mater Expert Review
	✓	Mar 21	National Research Council
	✓	Apr 5	Toyota Sustainability Conference
	✓	May 4	Montreux Global Energy Roundtable
	✓	May 20	Univ. of Chicago: Future of Transportation
	✓	Jun 14	Automotive News Green Car Congress
	✓	Jul 14	Aspen Institute Forum on Global Energy
	✓	Oct 3-5	North American Gas Summit
	✓	Oct 25	Subject Matter Expert Review
	✓	Dec 7	World Petroleum Congress

2012	✓	Jan 25-26	World LNG Fuels Conference
	✓	Jan 26	ARPA-E Natural Gas Vehicles Workshop
	✓	Feb 16	Society of Petroleum Engineers Student Summit
	✓	Mar 12	International Battery Seminar and Exhibit
	✓	Apr 2-4	Accenture: Operating the Interconnected Energy System
	✓	May 15	Alternative Clean Transportation Expo
	✓	Jun 4-6	Montreux Energy Roundtable
	✓	Jul 19-22	Aspen Global Energy Security Conference
		Sep 11-12	Toyota Sustainable Mobility Conference
		Sep 19-21	SAE Leadership Forum
		Oct 3-5	NGV Association Summitt
		Oct 17-18	Montreux CA Energy Roundtable
		Oct 24-25	Europe NGV Summit
		Nov 6-8	NGV Global Biannual Conference
		Nov 13-15	North American Gas Summit

Study Subgroup Leadership

Individual Fuel / Vehicle Options

Assessed potential to maximize commercial availability of individual supply chain technology pathways based on review of available reports and literature

Team / Subgroup	Leader	Organization
Biofuels	Todd Werpy	Archer Daniels Midland
Hydrocarbon Liquids	Chris Erickson	ExxonMobil
Natural Gas	Michael Gallagher	Westport Innovations
Hydrogen	Anthony Boccanfuso	University of South Carolina
Electric	William Reinert	Toyota
Engines & Vehicles – Light Duty	Alan Taub	General Motors
Engines & Vehicles – Heavy Duty	John Wall	Cummins

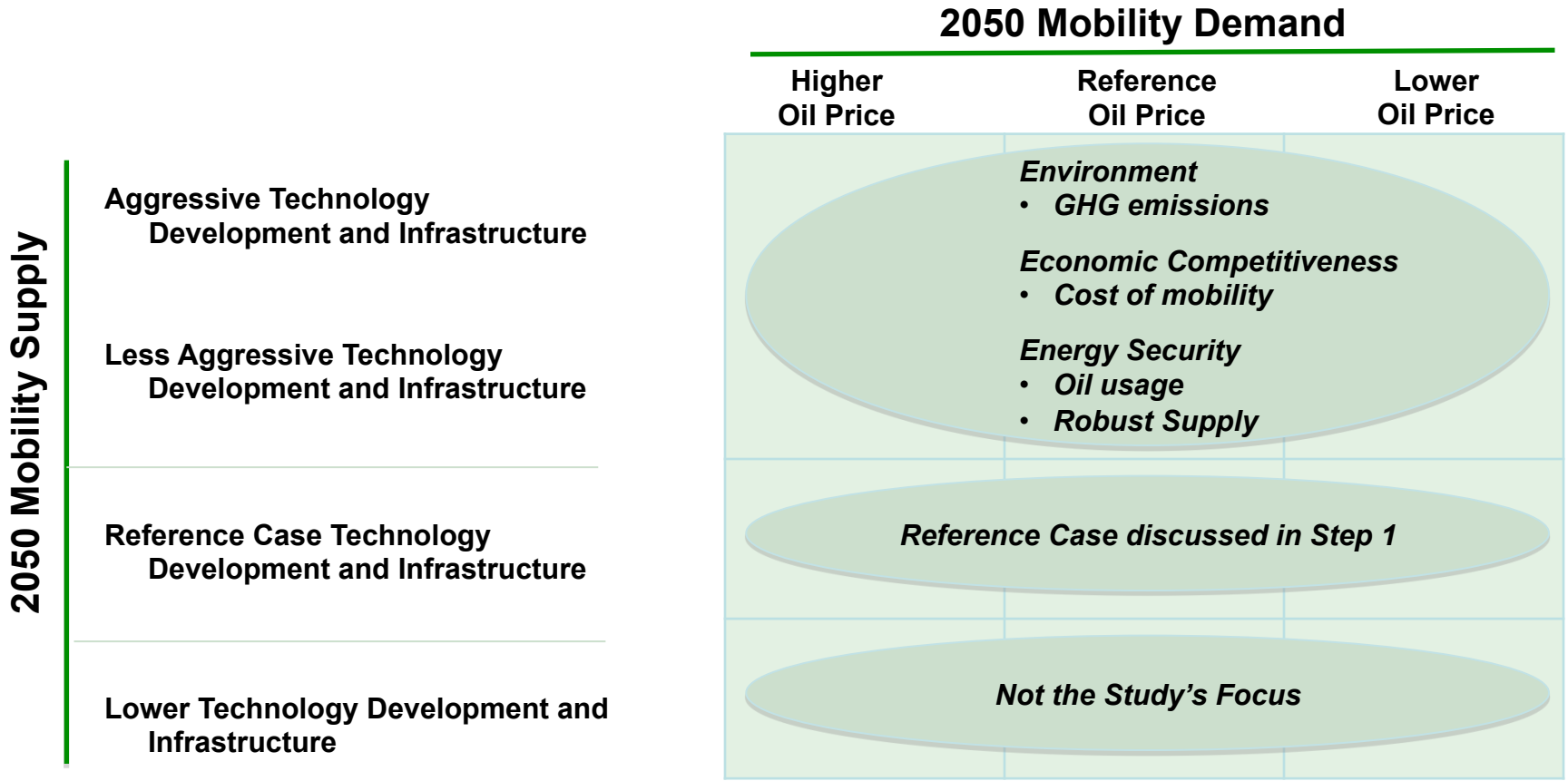
Demand / Supply Integration

Considered range of 2050 transportation demand for passenger and freight, and potential fuel/vehicle portfolio mixes meeting demand in an environmentally desirable, economically competitive, and energy secure way

Team / Subgroup	Leader	Organization
Report Integration	Peggy Montana	Shell
Data Integration	Gene Tunison	ExxonMobil
Integrated Vehicles	Clay Phillips	General Motors
Infrastructure	Charlie Schleyer	ExxonMobil
Green House Gas Emissions	Dave Rogers	Chevron

Demand / Supply Integration

- Describe an illustrative range of mobility demand for passenger and freight
- Describe potential commercially available fuel/vehicle portfolio mixes meeting 2050 mobility demand in an environmentally desirable, economically competitive, and energy secure way



FTF Study Findings

- **Fuel economy** can be dramatically improved in the light- and heavy-duty sectors through the advancement and application of existing and new technology. Internal combustion engine technologies are likely to be the dominant propulsion systems for decades to come, with liquid fuel blends continuing to play a significant, but reduced role.

- **Priority Technology hurdles** were identified that must be overcome for wide-scale commercialization of advanced fuel-vehicle systems by 2050. A broad portfolio of technology options provides the opportunity to benefit from potential Disruptive Innovations.

- **Infrastructure challenges** must be overcome for wide-scale commercialization of advanced fuel-vehicle systems. Options exist to facilitate concurrent development of alternative fuel vehicles and infrastructure, such as building on existing infrastructure, corridor-deployment, and multi-fuel vehicles.

- **GHG Emissions:** If technology hurdles and infrastructure challenges can be overcome, economically competitive low-carbon fuels and improvements in fuel economy will result in substantial reductions in GHG emissions. Additional strategies will be required to achieve a 50% reduction in GHG emissions relative to 2005 in the transportation sector by 2050.

- **Energy Security:** In the years ahead, the U.S. transportation sector could have access to a broad array of economically competitive fuel-vehicle system options, the diversity of which can contribute to our nation's energy security.

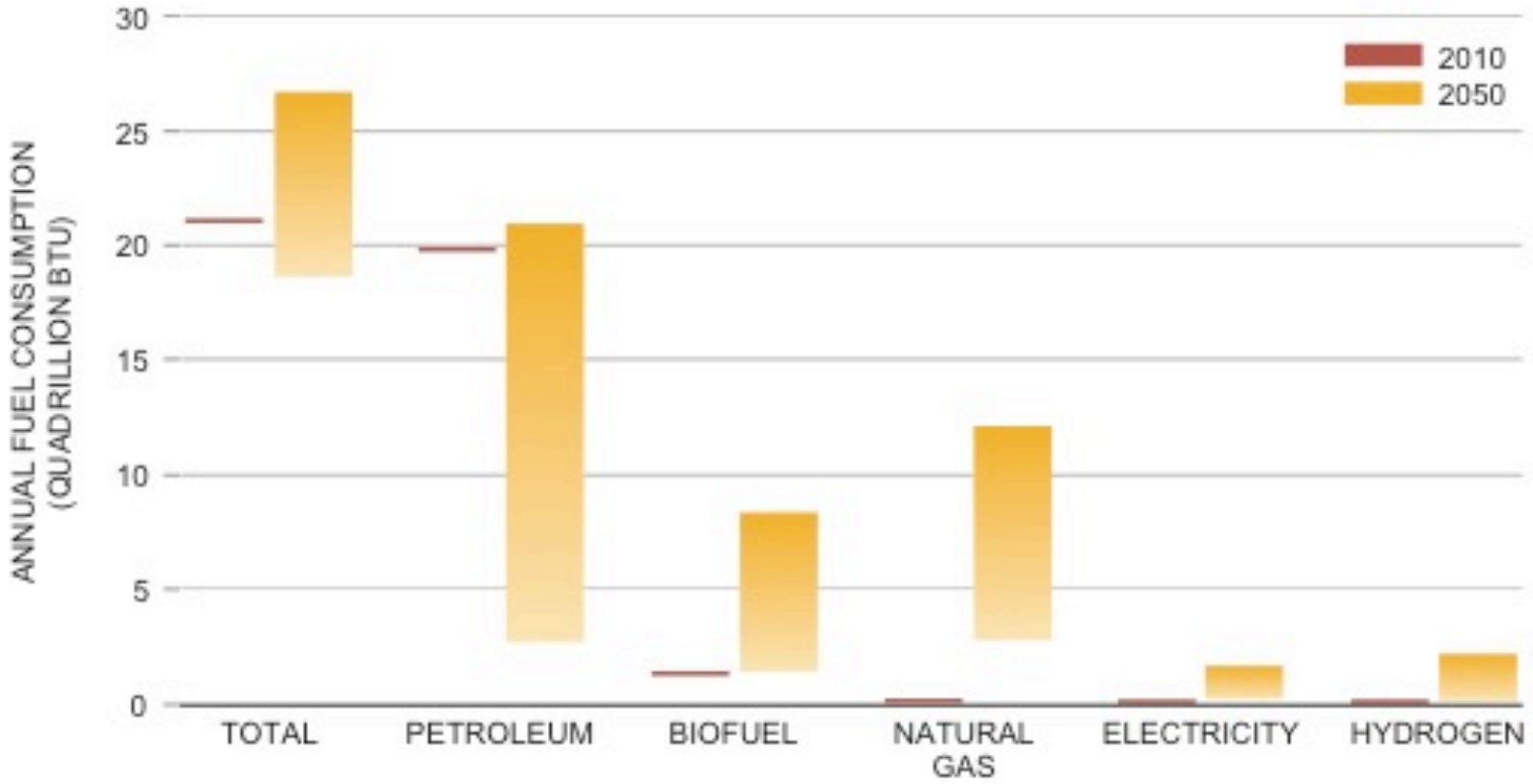
Fuel Economy

Fuel economy can be dramatically improved in the light- and heavy-duty sectors through the advancement and application of existing and new technology. Internal combustion engine technologies are likely to be the dominant propulsion systems for decades to come, with liquid fuel blends continuing to play a significant, but reduced role.

- Lightweighting, improved aerodynamics, reduced rolling resistance, and hybridization and electrification can improve all vehicle types
- Each fuel-vehicle system considered could become economically competitive by 2050
- This all comes at a cost, which impacts adoption in the market and therefore overall fleet fuel economy
- Internal combustion engine technologies are likely to remain dominant for decades to come

(continued)

Fuel Economy (continued)



Note: At equivalent fuel consumption (by energy), alternatives such as hydrogen FCEVs and electric vehicles can support 2-3x the miles due to their higher fuel economy.

Figure ES-10. Range of 2050 On-Road Fuel Use, Assuming All Alternatives are Successfully Commercialized

Subject Matter Experts

Area	Expert	Organization
Energy Security and Policy (Chair)	John Deutch	Massachusetts Institute of Technology
Agriculture – Biofuels	Robert Fraley	Monsanto
Applied Physics and Policy	Venkatesh Narayanamurti	Harvard University
Batteries/Electrochemistry	Yet-Ming Chiang	MIT/A123 Systems
Biotechnology	Jay Keasling	UC Berkeley/JBEI
Cryogenic Storage	Tom Drube	Chart Industries
Economics	Robert Topel	University of Chicago
Economics	Severin Borenstein	UC Berkeley
Energy Efficiency	Amory Lovins	Rocky Mountain Institute
Engines	John Heywood	Massachusetts Institute of Technology
Engines	Robert Dibble	UC Berkeley
Hydrogen/Fuel Cells	Henry White	University of Utah
Materials Science/Nanotechnology	George Whitesides	Harvard University
Solar Fuels	Daniel Nocera	Massachusetts Institute of Technology

Priority Technology

Priority Technology hurdles were identified that must be overcome for wide-scale commercialization of advanced fuel-vehicle systems by 2050. A broad portfolio of technology options provides the opportunity to benefit from potential Disruptive Innovations.

- Over 250 hurdles evaluated, with 12 Priority Technologies identified
- Systematic peer reviews by prominent academic and industry experts

Fuel/Vehicle system:	Priority Technology advancement:
Light-Duty Engines & Vehicles	- Low-cost lightweighting (up to 30% mass replacement)
Biofuel	- Hydrolysis
	- Fermentation of C5 and C6 sugars
	- Lignocellulose logistics/densification
	- Production of higher quality pyrolysis oil
	- Biotechnology to increase food and biomass
Light-Duty Electricity	- Lithium ion battery energy density
	- Lithium ion battery degradation and longevity
Light-Duty Compressed Natural Gas	- Leverage liquid ICE fuel economy technology
Light-Duty Hydrogen	- Compression and storage for dispensing
	- Fuel cell degradation and durability
Medium-/Heavy-Duty Engines & Vehicles	- Combustion optimization

Disruptive Innovation

Shift learning curves and improve economics, efficiency, GHG emission characteristics

- Low cost ultra-lightweighting – 50% to 70% mass reduction to improve fuel efficiency for light duty vehicles
- Advancement in lithium-ion battery technology or new battery chemistry – improve performance and reduce cost
- Advanced storage technologies for natural gas and hydrogen – reduce storage, compression costs
- Genetic engineering – increase feedstock yields, reduce costs for biofuels
- Non precious metal catalysts – reduce hydrogen fuel cell cost
- System level integration (Smart IT) – vehicle and infrastructure to enable autonomous driving, reduce congestion, improve efficiency of transportation systems

Wide-scale commercialization of alternative fuel-vehicle systems

- Priority Technologies required
- Disruptive Innovations not required

Infrastructure and Other Hurdles

Infrastructure challenges must be overcome for wide-scale commercialization of advanced fuel-vehicle systems. Options exist to facilitate concurrent development of alternative fuel vehicles and infrastructure, such as building on existing infrastructure, corridor-deployment, and multi-fuel vehicles.

Some examples are:

- Overcoming transition costs and other challenges in moving from one fuel-vehicle system to another
- Concurrent deployment of vehicle and associated fueling infrastructure investments
- Accelerating vehicle development cycle and market penetration
- Building on existing infrastructure minimizing initial investment
  - Electricity and biofuels leverage existing grid and liquid fuel infrastructure
  - Natural gas leverage fuel distribution infrastructure in heavy-duty freight corridors
  - Localized, corridor, or niche-application deployment can improve dispensing infrastructure use
- Flexible-fuel, bi-fuel and plug-in hybrids facilitate transition
  - Allow vehicle operation on fuel with more abundant dispensing
  - Build widespread availability of dispensing for the new fuel
- Significant hurdles to overcome and investment required for infrastructure and vehicle deployment

GHG Emissions

If technology hurdles and infrastructure challenges can be overcome, economically competitive low-carbon fuels and improvements in fuel economy will result in substantial reductions in GHG emissions. Additional strategies will be required to achieve a 50% reduction in GHG emissions relative to 2005 in the transportation sector by 2050.

- On a stand-alone basis, all light-, medium-, and heavy-duty vehicles have the potential to reduce per-mile GHG emissions by at least 40% in 2050, relative to 2005 average fleet levels
- Projected 2050 transportation demand, relative to 2005, counteracts per-mile GHG reductions
- The Study did not identify any portfolio of fuel-vehicle systems that provides a clear and cost effective path to lowering transportation sector GHG emissions in 2050 by 50% relative to 2005
  - In the LD segment, a limited number of portfolios achieved a 50% reduction in this segment
  - No MD/HD portfolios achieved a 50% reduction in this segment
- If disruptive innovations do not occur, then achieving a 50% GHG reduction will require additional strategies such as reducing electricity generation GHG emissions, reducing transportation demand, improving transportation system operating efficiency, and/or other actions

Energy Security

In the years ahead, the U.S. transportation sector could have access to a broad array of economically competitive fuel-vehicle system options, the diversity of which can contribute to our nation's energy security.

Creating Fuel Diversity

- Increased fuel efficiency, greater use of alternative fuels, and increased domestic supply of oil, gas, and biofuels create a diverse transportation fuel mix.

The Transition Period is Challenging

- New energy systems will be required to be as resilient to supply disruptions as existing U.S liquid hydrocarbon, natural gas, and electricity systems.
- The challenges of the transition period, while alternatives establish market share, can be eased through infrastructure mitigation strategies.

A Case for Optimism

- North American energy sources and technologies promise a diversity of economically competitive fuels and vehicles that will bolster America’s energy security.

FTF Study Recommendations

- Government should promote sustained funding and other resources—either by itself or in combination with industry—in pre-competitive aspects of the twelve Priority Technology areas identified, as well as in areas that could lead to Disruptive Innovations.
- There is a great deal of uncertainty regarding which individual fuel-vehicle systems will overcome technology hurdles to become economically and environmentally attractive by 2050. Therefore, government policies should be technology neutral while market dynamics drive commercialization.
- The Federal Government should take a leadership role in convening state, local, private sector and public interest groups to design and advocate measures to streamline the permitting and regulatory processes in order to accelerate deployment of infrastructure.
- When evaluating GHG emission reduction options, the government should consider full life cycle environmental impact and cost effectiveness across all sectors. It should also continue to advance the science behind the assessment methodologies and integrate lifecycle uncertainty into policy frameworks.
- Fuel, vehicle, and technology providers should consider existing or new voluntary forums that include federal and state governments and other stakeholders, to address concurrent development of vehicles and infrastructure.

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Reports and other information to be posted on NPC website – www.npc.org